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Range Cattle Production, 4

POST-WEANING PERFORMANCE

A Literature Review

By

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RANGE CATTLE PRODUCTION

A Literature Review

Section IV

POST-WEANING PERFORMANCE

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POST-WEANING PERFORMANCE

Normal Growth

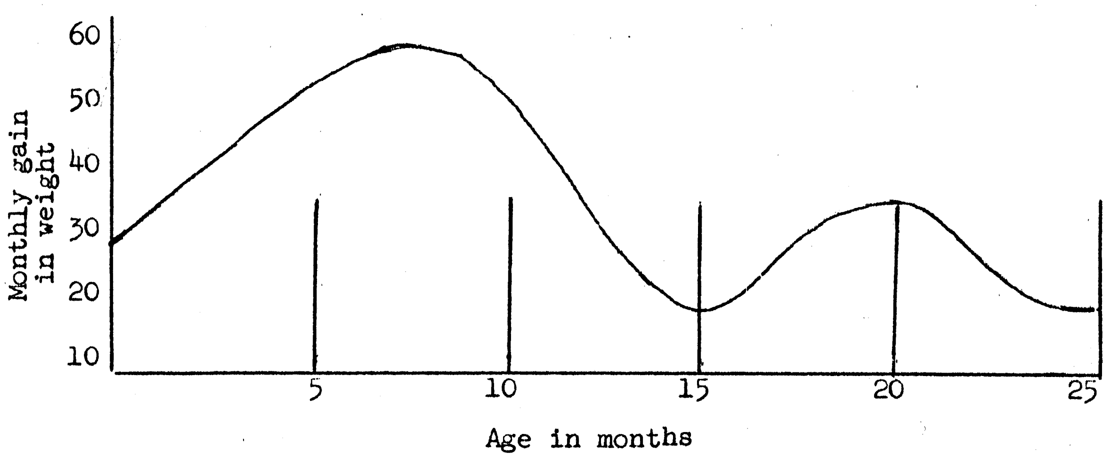
The curve of growth in volume or weight may be divided into two principal segments: first, a segment of increasing slope in which the velocity (time rate) of growth tends to be proportional to the growth already made (that is, the percentage rate of growth tends to be constant); and second, a segment of decreasing slope during which the velocity of growth tends to be proportional to the growth yet to be made to reach maturity.

In animals, the junction between these two segments, referred to as the major inflection, occurs at puberty. The segment of the growth curve which precedes the major inflection consists of several (perhaps five) epochs. The percentage rate of growth is constant for each of these epochs. The junctions between the epochs are relatively abrupt. Growth in higher animals is thus shown to be a more or less discontinuous process (37).

At a given age, the weight remaining to be made to reach the limiting or mature weight declines in a geometrical progression with age (36). The velocity of growth is proportional to a limiting "growth substance" which is used up in the course of growth according to the monomolecular law.

Smoothed curves of growth in weight of animals are usually sigmoid. They have the point of inflection not in the center of the curve, but where slightly over one-third of the mature body weight is reached. After the point of inflection, the course of growth in weight may be represented by an exponential equation. The curve of growth is approximately straight on semilogarithmic paper from 330 to 425 days, after which it decreases in slope (31).

Monthly gain increases from birth to five months of age, when the gain is the most rapid during the life of the animal. From this age it declines to the age of 15 months. This is followed by a second and last cycle with a maximum gain at about 20 months of age (35).



In Shorthorn and Angus cattle, weight for age is linear from 2 months to 10 months and again from 10 months to 24 months (44). The period of growth in weight or volume may be divided into two fairly distinct phases: first, a self-accelerating phase during which the time rate of growth increases with the increase in size of the organism; and second, a self-inhibiting phase during which the time rate of growth decreases with the increase in size of the organism (39). The method for determining equivalence of age with respect to growth in weight during the phase of growth following puberty has been described (38). The change in form of the animal due to increase in weight during growth is quite different from the change in form of mature animals during fattening or fasting (43). The use of a prediction chart for estimating the surface area of an individual may involve an error as high as ten per-cent of the true value.

TABLE I

Physiologically Equivalent Ages and Body Weights for Beef Cattle (104)

	Percent of Mature Weight						
	10	20	30	40	50	60	100
Average age, months	1.0	3.5	5.5	8.0	11.0	14.6	72
Average weight, lbs.	130	260	390	520	650	780	1300

Studies with small animals suggest the generalization that in a growing organism the magnitude of any part tends to be a specific function of the total body mass or of some portion so related to the whole (234). The "constant differential growth-ratio" shows that the relative growth-rates of an organ and the rest of the body remain constant during long periods: $Y = bx^k$ (131). In general, it is the vital organs used for maintenance of life which develop first, while the parts which are used for production--fat, muscle, udder, etc.--develop later. The "offal" parts of the body, such as the alimentary canal, head, and legs, develop early in life. The valuable parts, such as the loin, develop late (111).

Hereford-Shorthorn beef steers were divided into three groups (214):

- Group I - full fed for maximum growth
- Group II - maximum growth without fattening
- Group III - poor growth (average 0.69 lb. daily gain for 2 years)

The weight-age curves showed that for all groups growth was linear from birth to 15 months, linear from 15 to 30 months, and linear from 30 to 40 months. The monthly gains in live weight showed the following results:

- Groups I and II, linear 2 to 5 months; flat 5 to 11 months
- Group I - sharp rise 16 to 30 months with a linear decline from 13 to 21 months
- Group II - irregular decline from 11 to 33 months
- Group III - irregular decline 3 to 40 months

In a study of the retarded growth and mature size of beef steers it was found that the length of the period of growth of normal beef steers is about six years (123). A low plane of nutrition lengthened the growing period, in one case to nine years. Severe undernutrition of cattle for the first three years tended to reduce their mature size, although the retardation of growth does not result in abnormalities in conformation. The extent of retardation of skeletal growth was much less affected than the extent of growth in weight. Less opportunity was offered for modifying the course of skeletal growth, particularly growth in height, than of growth in weight (44).

Undernutrition has its most pronounced effect first on the less essential portions of the body. The skeleton and essential organs continue to grow at the expense of muscular tissue and fat (125).

In a rearing experiment employing identical heifer twins, the twins were divided into four groups. In all groups one twin of each pair received a normal plane of nutrition according to age and growth capacity, while the other twin received 60, 80, 120, and 140 percent, respectively, of that amount. The following results were obtained (117)(118):

1. No difference in the various twin pair reactions to the different feeding could be demonstrated in spite of the great differences in the type of the twins.

2. Rearing intensity strongly influences the rate at which the body develops. Since growth proceeds continuously to aging and death, this means that rearing intensity has also:

   (a) Considerable influence on the length of life

   (b) Within the limits of the feeding levels employed in this and in previous rearing experiments with identical twins, rearing intensity has practically no influence on size and proportion of the body at maturity

3. This means that the development of the body is so controlled by the genotype that, irrespective of the feeding intensity, it reaches the same end-point. This implies that studies of heritability of growing animals give a very misleading result with respect to the genetic determination of growth. Heredity, and not intensity of feeding, determines the bodily development at maturity.

4. Maintenance requirements for growing animals cannot be calculated from accepted formula since the maintenance requirements follow a rather complicated function into which, in addition to weight, enter age, feeding intensity, and the genetic-growth characteristics as independent variables.

A high plane of nutrition has been generally accepted as necessary for proper development of the growing animal. In a discussion of beef cattle it has been stated that the head and legs are proportionally large in the calf and as the beef qualities develop they become proportionally smaller and the loin becomes proportionally larger (109)(112). For the full expression of these developmental characters, a high plane of nutrition is necessary, for, if it is not available, the later maturing and more valuable parts are not developed.

An experiment was designed to obtain data on the effectiveness of supplemental feed supplied at different periods of the year and at different stages of development of the animal (103). It was found that feeding calves a supplement immediately after weaning so that the animals gained about one pound daily had a marked effect on subsequent performance. Data on grades and proportions of wholesale cuts for each carcass showed that this group on the average had an advantage. Although there was no difference in the final condition of the animals, those receiving supplement yielded relatively more hind quarter.

It has also been noted that the velocity of growth, taken as the reciprocal of the time required to attain a given size or stage of development, is apparently affected by temperature (66).

Breed improvement for beef consists of rearing animals on a high plane of nutrition and selecting for breeding purposes those which go through the age change in proportions quickest and to the fullest extent (110).

Ideal size in general can be defined as the largest size which will, on a given plane of nutrition, attain the required carcass composition (degree of fatness) at the desired market weight. Conformation judging in a calf must give consideration to the relative maturity of the various portions of the body. If a calf is exceptionally thick and its proportions approach those of an average mature animal, it is destined to become either an exceptionally thick-bodied animal of moderate size or a moderately thick small animal (102).

TABLE II

Weight and Measurements of Desirable Individual Hereford Cattle at Different Ages in Good Growing or Breeding Condition, but not Fitted for Show or Sale (102).

Age	Weight (lbs.)	Ht. at Withers (inches)	Heart Girth (inches)	Head Width (inches)	Head Length (inches)
Females					
2 weeks	105	26.4	30.4	5.1	9.9
$8\frac{1}{2}$ months	500	37.0	52.8	7.3	14.1
$12\frac{1}{2}$ months	705	39.0	60.9	7.9	16.0
16 months	825	43.4	63.8	8.3	16.3
20 months	935	45.6	68.6	8.5	16.6
24 months	982	46.1	69.4	8.6	17.1
36 months	1170	48.1	74.8	9.7	18.3
48 months	1340	48.5	78.0	9.7	18.6
60 months	1310	48.5	77.0	9.7	18.9
Males					
1 week	93	26.0	29.9	4.9	9.7
4 months	350	34.7	46.9	6.9	13.2
8 months	615	39.8	58.0	8.1	15.2
13 months	845	42.6	65.0	8.9	17.2
16 months	1025	44.9	69.8	9.3	17.9
20 months	1215	48.1	74.0	8.6	18.5
24 months	1420	49.6	78.4	10.1	19.1
36 months	1615	48.9	80.0	10.7	19.7
60 months	1755	47.3	84.0	10.9	20.3
72 months	1910	47.3	86.0	11.2	20.4

Metabolism

A summary of the relationship of body size and metabolic rate has been presented (156).

1. Among homeotherms, from mice to cattle, metabolic rate and body size are correlated.

2. The metabolic rate of large and small homeotherms is more nearly proportional to the area of their respective body surfaces than to their body weights.

3. Theory of surface law: In natural selection those animals prove to be better fit whose rate of oxygen consumption is regulated so as to permit the more efficient temperature regulation as well as the more efficient transport of oxygen and nutrients.

4. The metabolic level of an animal may be characterized as the metabolic rate per kg.$^{3/4}$.

5. The unit of metabolic body size is useful for expressing levels of food intake and of animal production; it is a sound basis for comparing food capacity and production capacity of animals that differ in body size. Relative food capacity (maximum rate of food intake per kg.$^{3/4}$) should be among the most important criteria for selecting food utilizers.

The metabolism per unit weight is very high at the beginning and declines with increasing weight. The rate of decline in metabolism per unit weight becomes less and less as the animal increases in weight, so that finally the metabolism per unit weight becomes practically constant (41).

The metabolism increases with the 0.6 power of body weight, as does surface area, but ~~the~~ ventilation rate increases with the 1.0 power of body weight. The oxygen removed from the inhaled air is about 4 percent at 100 lbs. live weight and 2 percent at 1000 lbs. live weight (42).

The ratio $\frac{\text{metabolic rate}}{\text{brain weight}}$ tends to be the same for small and large animals;

the ratio $\frac{\text{metabolic rate}}{\text{body weight}}$ on the other hand, declines rapidly with increasing weight (45). This may imply the presence of a close physiologic interrelation between brain weight and metabolism.

TABLE III

The Basal Metabolism of Various Mammals Compared (213)

		Basal Metabolism in Cal. per		
Animal	Weight (kg.)	Kg. Day	Sq. M. Day	Kg. 0.73 Day
Steer	500	12	1,090	65
Man	65	25	920	78
Guinea Pig	0.41	86	710	68
Mouse	0.021	170	530	61

Feed Efficiency

The need for a simple but accurate method of measuring and comparing the efficiency with which animals utilize feed for growth has been recognized for a long time (115). A method of measuring the efficiency of utilization of feed for growth is described. It is emphasized that satisfactory results are obtained only when the utmost care is exercised in measuring the feed consumption and the resulting gains in live weight.

This method is based on the fact that the equation of the curve of diminishing increment expresses with a high degree of accuracy the relationship between live weight and feed consumption. The equation of the curve of diminishing increment, as applied to the relationship, may be written:

$$w = A - Be^{-kf}$$

w is the live weight after any quantity of feed, f, has been consumed;
A is the maximum live weight attainable as a result of growth, but not as a result of fattening;

B is the total gain in live weight that is made in reaching the maximum live weight;
e is the base of the natural system of logarithms;
k is a constant which is a measure of the rate of decrease in the efficiency of feed utilization;
f is the quantity of feed that is required for attaining any live weight, w.

This equation can be written:

$$\frac{dw}{df} = kA - kw.$$

$\frac{dw}{df}$ may be defined as the efficiency (E) of feed utilization for growth because it represents the gain in live weight per unit weight of feed consumed. If E is written in place of $\frac{dw}{df}$ and c in place of kA, the equation becomes $E = c - kw$.

E is the efficiency of feed utilization for growth (the gain in the live weight per weight unit of feed consumed);
c is the maximum efficiency of feed utilization for growth;
k is a measure of the rate of decrease in the efficiency of feed utilization;
w is the live weight at which the efficiency of feed utilization is being measured.

Since the equation $E = c - kw$ is an equation of a straight line it may be written:

$\bar{E} = c - k\bar{w}$
$\bar{E}$ is the average efficiency of feed utilization while the live weight is changing from w_1 to w_2 as a result of the quantity of feed $(f_2 - f_1)$ having been consumed;
c and k same description as before;
$\bar{w}$ is the average of any two live weights, such as w_1 and w_2.

An example of the use of this method is presented.

Growth per feed unit decreases with age for different planes of nutrition (117)(118). There is no fundamental relation between size (potential mature size) and efficiency of feed utilization (102).

TABLE IV

Daily Intakes of Total Air Dried Feed and Total Digestible Nutrients at Physiologically Equivalent Body Weights for Beef Cattle (104)

	Percent of Mature Weight						
	10	20	30	40	50	60	100
Total daily feed, lbs.			11.7	14.5	16.7	18.7	19.5
Daily feed intake, % of body weight			3.0	2.8	2.6	2.4	1.5
Daily intake of digestible nutrients, lbs.			6.6	7.7	8.8	9.3	9.5
Digestible nutrients, % of total feed			58	55	53	51	50

TABLE V

Protein, Calcium, and Phosphorus Allowances Expressed as Percent of Total Digestible Nutrients for Beef Cattle (104)

	Percent of Mature Weight						
	10	20	30	40	50	60	100
Digestible protein, % of T.D.N.			13.6	11.6	10.2	9.7	7.5
Calcium, % of T.D.N.			0.67	0.55	0.45	0.41	0.30
Phosphorus, % of T.D.N.			0.50	0.44	0.38	0.35	0.30

TABLE VI

Vitamin Allowances Expressed in Amounts per Pound of T.D.N. for Beef Cattle (104)

	10	20	30	40	50	60	100
Carotene mg. per lb. of T.D.N.			3.5	3.9	4.3	4.8	8.2
Vitamin A, I.U. per lb. of T.D.N. for beef cattle			1700	2000	2100	2400	4100

Allowances/per 100 pounds of body weight at all ages: 6.0 mg. carotene, 3000 I.U. vitamin A.

From the standpoint of total feed required to produce a unit of product, greatest efficiency is obtained from a high plane of nutrition with continuous growth and development (103). The amount of feed that will make a steer gain two pounds a day is approximately twice the amount necessary merely to maintain him (230). Improvement in diet results in a much earlier maturity. Since the cost of maintaining animals is by far the largest item in the cost of growth, it seems advisable to grow animals rapidly and thereby save much of the cost of maintenance (40).

A study was made, with six pairs of monozygotic twin steers, of the relative effects of continuous and of interrupted growth (279).

One member of each pair of twins was subjected to a retardation of growth and the other was fed liberally. Two experimental animals were fed at each of the following energy levels: (1) maintenance, or about 50 percent of a liberal ration, (2) 62 percent of a liberal ration, and (3) 75 percent of a liberal ration. The two lower allowances were fed the steers for 6 months between the ages of 6 and 12 months. The 75 percent ration was fed for a period somewhat longer than 6 months. At the end of the period of reduced feeding the retarded animals were fed a liberal ration; the controls were given liberal allowances throughout the experiment.

The steers gained a pound a day on the 75 percent ration, 0.5 pound a day on the 62 percent ration, and neither gained nor lost much weight on the maintenance allowance.

After the period of reduced intake ended, all the retarded animals gained weight rapidly and economically.

Each steer was slaughtered when it reached a weight of about 1000 pounds. Although in most cases the retarded animals reached slaughter weight from 10 to 20 weeks later than did their co-twins, the former attained this weight on approximately the same intake of energy as the latter. This rather surprising result is explained by the fact that after reduced feeding ended, the retarded animals made more economical gains than did their co-twins.

Carcass grades and meat quality of the retarded animals were not lowered appreciably by the period of low-energy intake. The quantity of lean meat in the carcass was not decreased by interruption of growth.

It is concluded that under conditions of feed scarcity beef cattle between the ages of 6 and 12 months can be carried at an energy level as low as maintenance, if the nutritional needs other than those for energy are supplied, without loss later in efficiency of feed utilization, meat quality, or in the proportion of lean meat to fat and bone in the carcass.

In breeding for efficiency of food utilization, the total net energy efficiency, $\frac{\text{energy in animal's product}}{\text{energy in the total food}}$, is a suitable characteristic for selecting good utilizers of food (155). The total energy efficiency may be determined directly by measuring the energy content of the product including changes in body substance. For such determinations, it is desirable to establish standard food mixtures which should be reproducible and nearly optimum for the type of animal studied. When total digestible nutrients are used as a measure of feed energy, the formula (207):

digestible protein + digestible carbohydrate + digestible fat (x2.25)

should be changed to read:

digestible protein (x1.36) + digestible carbohydrate + digestible fat (x2.25)

It has also been suggested that total digestible nutrients is not an accurate measure of the productive energy value of feed. This system overestimates the value of roughages (199).

The net energy per unit of ration intake declines with an increasing plane of nutrition largely on account of the increase in specific dynamic action (46).

TABLE VII

Estimated Average Requirement of Minerals by Growing Calves (210)

Calcium	0.27 percent of dry ration
Phosphorus	0.19 percent of dry ration
Magnesium	0.07 percent of dry ration
Cobalt	0.07 p.p.m.
Copper	3 p.p.m.
Iodine	0.09 p.p.m.

TABLE VIII

Percentage of Total Feed Consumed by all Livestock in the United States from Different Sources, Average 1942-46 (137)

	Percent
Corn (grain)	24.5
Other grain	11.5
Commercial by-products	7.4
Seeds and skim milk	1.7
Hay	15.6
Silage and beet pulp	2.5
Stover	2.7
Pasture	34.1

TABLE IX

Percentage of All Feed Consumed by Each Class of Livestock, Average 1942-46 (137)

Feed	Dairy Cattle	Beef Cattle	Sheep	Hogs	Poultry	Horses & Mules
All feed, including pasture	31.3	21.0	7.1	17.9	11.4	9.7
All roughage	42.1	31.3	12.3	.8	1.0	12.0
Corn, including corn in silage	15.1	10.8	.8	47.1	17.1	6.8
Corn, excluding corn in silage	10.4	10.9	.8	50.1	18.2	7.2
Oats	30.1	5.0	2.0	20.4	21.5	19.0

TABLE X

Percentage of All Feed Derived from Different Sources, Average 1942-46 (137)

Feed	Dairy Cattle	Beef Cattle	Sheep & Goats	Hogs	Poultry	Horses & Mules
Corn	8.1	12.8	2.6	69.2	39.2	18.1
Other grain	7.7	2.5	2.4	17.4	31.5	13.5
Commercial by-products	8.4	2.3	1.0	6.2	22.7	.4
Seeds and skim milk	2.0	.6	-	4.6	1.9	-
Hay	26.5	14.1	12.5	-	-	33.1
Silage and stover	9.9	7.5	3.1	-	-	2.3
Pasture	37.4	60.2	78.4	2.6	4.7	32.6

TABLE XI

Total Digestible Nutrients Consumed in Putting on Each 100 Pounds of Gain in Fattening a Choice Feeder Steer from 400 to 1100 Pounds (137)

Change in Weight	T.D.N. Consumed per 100 Lbs. Gain in Weight
400 to 500 lbs.	402
500 to 600 lbs.	435
600 to 700 lbs.	489
700 to 800 lbs.	560
800 to 900 lbs.	655
900 to 1,000 lbs.	787
1,000 to 1,100 lbs.	988

TABLE XII

Example of Metabolism--Steers and Heifers (Summary)(47)

	Age Days	Wt. Kgs.	Heat*	Pulse
Steer 808	100	65.8	2794	
	130	78.9	3382	
	170	108	4343	
	220	161	5947	
	275	197	5050	
	340	247	6518	
	360	269	6269	69
	405	308	8400	96
	450	327	6317	72
	500	354	5722	63
	531	363	6662	60
Heifer 810	100	59.4	2711	
	128	74.4	3974	
	167	101	4094	
	220	146	5174	
	276	189	5875	
	339	217	4522	
	361	228	6288	72
	405	250	6298	72
	450	275	6374	78
	500	313	7795	76
	530	340	7718	72

*Heat refers to heat production in cal. for 24 hrs. (total)

TABLE XIII

Pounds of Total Digestible Nutrients Required Daily by Beef Calves Weighing 200 to 800 Pounds to Maintain Weight and to Make Regular Daily Gains (278)

Weight of Animal	T.D.N. Required (Pounds) To Maintain Weight	1/2 lb.	3/4 lb.	1 lb.	1-1/2 lbs.	2 lbs.
200	1.9	2.6	3.0	3.4	4.2	-
300	2.5	3.5	4.0	4.5	5.5	6.5
400	3.0	4.2	4.8	5.4	6.6	7.8
500	3.5	4.9	5.6	6.3	7.7	9.1
600	3.9	5.5	6.3	7.1	8.7	10.3
700	4.4	6.1	7.0	7.9	9.6	11.4
800	4.8	6.7	7.6	8.6	10.5	12.4

TABLE XIV

Daily Average of Nutrients Consumed, Total Nutriment, and Nutriment to One Pound Gain During Each 100 Pounds Increase in Weight (106)

Weight From	Weight To	Dry Matter (lbs.)	Protein (lbs.)	CHO (lbs.)	Fat (lbs.)	N.R. 1:	Total Nutriment	Nutriment to 1 lb. Gain
100	200	2.60	.437	1.336	.143	3.8	2.094	2.25
200	300	6.10	.708	3.154	.161	5.0	4.224	3.19
300	400	8.13	.773	4.161	.219	6.0	5.427	3.76
400	500	9.81	.867	5.032	.259	6.5	6.482	4.29
500	600	11.88	1.034	6.096	.331	6.6	7.875	4.26
600	700	13.30	1.198	7.039	.359	6.6	9.054	5.29
700	800	15.02	1.402	7.639	.382	6.1	9.901	5.53
800	900	16.18	1.551	8.325	.424	6.0	10.830	7.08
900	1000	17.32	1.616	9.171	.468	6.3	11.840	7.31
1000	1100	17.88	1.580	9.741	.462	6.8	12.361	8.08
1100	1200	18.58	1.614	10.298	.528	7.1	13.100	8.85

The food for human consumption that is produced from the feed utilized in fattening cattle is greater than is indicated by the gain in live weight. During the fattening process the percentage nutrient content of the whole carcass is materially increased. This fact is frequently overlooked when comparisons are made between the efficiency of feeding cattle for fattening and the efficiency of feeding other kinds of livestock (219).

Efficiency in feed utilization during the fattening period, measured by the aggregate quantity of edible protein, ash, and fat produced per unit of feed, increases slightly until approximately choice (revised standard) slaughter grade is reached.

Pigs, dairy cows, laying hens, and broilers are much more efficient in protein production than are steers or lambs (208).

The steer and lamb show a low efficiency in the production of all nutrients on a gross energy-intake basis. The primary reason for this is that their rations are of much lower digestibility because of the large amounts of roughage consumed. This is food that man cannot eat, and thus figures based on gross energy without regard to source markedly overstate the waste by ruminants of man's food supply.

TABLE XV

"Feed Units" Required to Produce 2600 kcal of Human Food (208)

Animal Product	All Feed (lbs.)	Concentrates (lbs.)
Pork	7.7	7.2
Milk (dairy cows)	9.3	2.3
Eggs	21.9	20.6
Poultry Meat	29.9	27.1
Beef	71.6	15.2
Lamb	74.5	4.7

"Feed unit" represents the common denominator of all kinds of feed and equals the feed value of one pound of average corn.

The "all feed" column reveals the order of efficiency calculated for the conversion of gross calories of feed and the edible calories of production. The "concentrates" column shows the requirements for concentrates that otherwise could be used by man. On this basis, the dairy cow, which requires only one-quarter of its total feed as concentrates, is much more efficient than the pig, which excels on the "all feed" basis. The lamb, which is the least efficient on the latter basis, also goes ahead of the pig when concentrates only are considered. The beef animal also makes a relatively much better showing when concentrates alone are considered, whereas poultry depends almost entirely on concentrates and, therefore, is the least efficient.

Body Composition

In order properly to evaluate the gain of an animal and to establish the real feed efficiency, it is necessary to know the body composition of the animal. The amount of fat is important since it does indicate more accurately how the feed consumed was utilized. The body composition in the live animal is estimated on the basis of water content; the fat is then computed.

A method for determining the body water content of cattle by dilution of administered antipyrine has been described (190). The body water content on 30 head of cattle ranged from 43.9 to 63.3 percent, corresponding to a range in body fat of 13.9 to 40.1 percent. The specific gravity ranged from 1.017 to 1.070 (189). The following correlations were obtained:

Body specific gravity/fat content	-.956
Body specific gravity/water content	+.984
Specific gravity of carcass/specific gravity whole animal	+.989
Specific gravity carcass/specific gravity 9 - 10 - 11 rib cut	+.950
Specific gravity whole animal/ " " " " " " "	+.954

Based on the mean value of 72.6 percent water in the lean body mass of cattle, the following theoretical equations were derived showing gravity and body water and body fat (189).

$$\text{Percent fat} = 100 \left(\frac{4.802}{\text{specific gravity}} - 4.366 \right)$$

$$\text{Percent water} = 100 \left(3.896 - \frac{3.486}{\text{specific gravity}} \right)$$

The need for proper technique is extremely important, but the method appears to have practical value (11).

In a study of 165 cattle, the relation of spleen, liver, heart, kidney, and pancreas to lean-body mass and empty-body weight were studied (191).

There is a very high positive correlation between the organ weights and the weights of the empty-body and lean-body mass. All organs studied were about equally reliable in their predictive value for a population limited in age and weight. The liver appears to be a better indicator than the other organs.

Other methods for determining water content of the animal's body have been proposed. A method is described which permits the accurate estimation of water retention from the retention of sodium and potassium. Analysis of the tissues of foetal, young, and mature cattle showed that their water content could be predicted from the equation:

$$\text{Water (gm.)} = 0.2922 \text{ Na(mgm.)} + 0.1471 \text{ K (mgm.)}$$

A rapid titrimetric method that does not appear to be difficult for determining the water content of animal tissues is described (64). Blood and solid material, 100 to 250 mg. of tissue, are used. The method agrees very closely with results obtained by oven drying.

Creatinine excretion and the separable lean content of the 9, 10, 11th rib cut of 18 Hereford steers have been determined (198). The creatinine excretion per unit of body weight was significantly correlated with the percent separable lean in the soft tissue of the sample ($r = +0.67$). It was found that while there appeared to be little correlation between these two measures within carcass grades, the correlation between grades was good. Although the correlation coefficient is probably not high enough to enable one to predict small differences between individual animals, it does appear possible that creatinine excretion may be useful as an indication of differences in the lean content of the bodies of groups of animals differing by one or more slaughter grades.

The separable fat of the rib sample can be predicted accurately from the specific gravity of the whole sample by use of the equation:

$$F = \frac{1.155 - G_W}{0.261}$$

where F is the proportion of separable fat in the rib cut and G_W is the specific gravity of the whole cut.

The use of radioactive urea is also useful in measuring total body water since only a negligible amount of urea is lost after administration (188). In humans, a sodium thiocyanate solution injected intravenously is used to calculate total body water, cell mass, and body fat (209). Details of the procedure and the formula are given.

Antipyrine and deuterium oxide have been compared for determination of body water in edematous subjects (129). It was concluded that the deuterium volume is uniformly greater than the antipyrine volume. Although both methods reflect changes that agree well with observed weight losses, the deuterium method is considered more accurate.

Effect of Age, Sex, and Breed on Performance

Good quality yearling steers and open heifers were compared for beef production (261). The following results were obtained:

(a) Steer calves full fed an average of 182 days gained 41.2 pounds more than similar heifers fed the same way

(b) Heifers showed suitable market finish 30 to 40 days sooner than the steers

(c) Heifers full fed 182 days required 11 percent more grain and 25 percent more roughage than steers to produce 100 pounds gain

Bulls will gain 0.3 to 0.5 more than heifers (68).

Two-year-old steers, yearling steers, and steer calves were compared with spayed and open heifers of similar ages (96). The following results were obtained:

(a) In all cases, steers made greater and more economical gains than spayed heifers. Yearling open heifers made slightly greater and more economical gains than yearling steers.

(b) In all cases, open heifers made greater and more economical gains than spayed heifers.

(c) Heifers, both open and spayed, fatten faster than steers.

(d) Two-year-olds made greater gains than yearlings and the yearlings exceeded the calves. The economy of gain was the reverse. These age differences were similar in both sexes.

TABLE XVI

Summary of Age and Sex Trials (96).
175-Day Feeding Period

	Lot Number							
	1	2	3	4	5	6	7	8
No. of animals	11	11	14	14	14	19	17	17
Ave. initial wt.	793	721	635	589	570	382	386	390
Ave. final wt.	1163	1069	1002	919	946	745	677	727
Ave. daily gain	2.12	1.99	2.10	1.89	2.15	2.07	1.66	1.92
Feed per 100 lbs. of gain:								
Corn	844	869	702	723	665	502	619	544
Alfalfa hay	266	285	340	380	340	287	355	310

Lot 1 Two-year-old steers
Lot 2 Two-year-old spayed heifers
Lot 3 Yearling steers
Lot 4 Yearling spayed heifers
Lot 5 Yearling open heifers
Lot 6 Steer calves
Lot 7 Spayed heifer calves
Lot 8 Open heifer calves

No advantage occurs from spaying heifers that are going into the feed-lot. Pregnancy in cattle does not cause increased appetite or food consumption (121).

It has been noted (76)(120) that with mice and rats pseudopregnant animals gain at nearly the same rate as those going through normal pregnancy. It thus appears that the fetus and membranes are responsible only in part, if at all, for the increased growth rate of the pregnant animals.

The paired feeding method was used on 16- to 18-month-old heifers (249). The experiment started when one heifer of a pair was bred and 150 days later the animals were slaughtered. Bred heifers spent more time lying down, were less active, and had quieter dispositions than open heifers. The bred heifers had better appetites than open heifers. When kept at the same level of feed consumption, bred and open heifers showed no significant difference in rate of gain.

In a comparison of bulls and steers in the feed lot (5) it was shown that bull calves returned more than steers because of superiority in gain and the small price differential in the carcasses. The feed-lot performance of steers castrated at birth or at weaning was practically identical (157). Bulls gained at a rate of 0.23 to 0.48 pound per head daily faster than steers (158).

The difference in skeletal growth between types and between sexes is said to explain the difference in gains between types and between sexes (18).

A number of experiments have been conducted to compare the feed-lot ability of purebred and crossbred animals. Since the results cannot be compared between stations, the results of each test are summarized.

(a) (81)

	Ave. Daily Gain
Purebred Holstein	2.26
Purebred Angus	2.15
Angus x Holstein	1.97

(b) (82)

	Ave. Daily Gain
Purebred Holstein	2.37
Purebred Angus	2.19
Angus x Holstein	2.05

(c) (93)

	Ave. Daily Gain
Purebred Angus males	1.64
Purebred Angus females	1.59
Purebred Hereford males	1.72
Purebred Hereford females	1.61
Hereford x Angus males	1.73
Hereford x Angus females	1.63
Angus x Hereford males	1.75
Angus x Hereford females	1.62

(d) (134)

	Ave. Daily Gain	Feed/100 lbs. Gain
Steers--104-day test		
Brahman	1.68	959
Hereford	2.21	912
Braford	2.26	943
Steers--197-day test		
Hereford	2.31	771
Braford	1.96	881
Shorthorn x Hereford	2.19	815

(e) (7)

	Ave. Daily Gain	Gain/100 lbs. T.D.N.
Steers		
Purebred Angus	1.19	11.45
Brahman x Angus	1.27	11.32
Angus x (Brahman x Angus)	1.20	10.45
Africander x Angus	1.25	10.85

(f) (244)

	Ave. Daily Gain
Purebred Angus	1.77
Angus x Arkansas native	1.69
Arkansas native	1.52

(g) (135)

	Ave. Daily Gain	Feed/100 lbs. Gain
First Year, 205 days		
Brahman	1.64	916
Hereford	2.15	907
Braford	1.91	968
Second Year, 197 days		
Hereford	2.18	796
Braford	1.89	899
Shorthorn x Hereford	2.10	820

(h) (206)

Summary of 168-Day Rate-of-Gain Test

Breed and Sex	Daily Gain (lbs.) Range	Average
Buffalo bulls	1.01 to 1.99	1.34
Buffalo heifers	0.83 to 1.34	1.09
Cattalo bulls	1.31 to 2.53	1.89
Cattalo heifers	0.98 to 1.79	1.47
Cattalo bulls (inbred)	1.73 to 2.23	1.95
Cattalo heifers (inbred)	1.22 to 1.84	1.59
Highland x Hereford steers	1.76 to 2.47	2.10
Hereford steers	1.58 to 2.29	1.92
Hereford bulls	1.84 to 2.59	2.27
Hereford heifers	1.67 to 2.08	1.87

(i) First cross Brahman calves gained 10 to 20 percent more rapidly than calves by beef-breed sires (33)(34).

(j) Crossbred Brahman-Hereford and Brahman-Shorthorn steers were compared with typical Hereford and Shorthorn steers with respect to feed-lot performance. No significant differences were found in the total quantities of feed consumed in proportion to weight of the steers (21).

(k) (164)

	Ave. Daily Gain	Gain per 100 lbs. T.D.N.
Purebred Hereford 1939-40	1.68	17.68
Shorthorn x Hereford 1939-40	1.77	17.80
Purebred Hereford 1940-41	1.81	18.30
Shorthorn x Hereford 1940-41	2.08	18.49
Purebred Hereford 1942-43	1.94	18.43
Angus x (Shorthorn x Hereford) 1942-43	2.08	17.62
Purebred Hereford 1943-44	1.79	18.17
Angus x (Shorthorn x Hereford) 1943-44	1.93	17.20
Purebred Hereford 1945-46	1.92	19.25
Hereford x (Angus x (Shorthorn x Hereford)) 1945-46	2.23	19.28
Purebred Hereford 1946-47	2.28	18.76
Hereford x (Angus x (Shorthorn x Hereford))	2.41	17.49

Comparison of Large and Small Type Cattle

The "large" type is often referred to as "regular" or "conventional", the "small" type as "compress" or "pony".

The following four measurements have been suggested as possible guides in differentiating between the two types of Hereford steers at about 12 months of age (239):

(a)	Length of cannon bone	20.1 centimeters
(b)	Height of chest	48.5 "
(c)	Hip height	107.3 "
(d)	Wither height	101.8 "

It was concluded that the "small" type steers have a mildly hyperfunctioning thyroid as compared with "conventional" type (200).

The results of feed-lot trials indicate that the "large" type eats more and gains significantly faster than the "small" type (4)(58)(183)(241)(252)(253)(259)(268). These reports show that there is no consistent difference between the types in the amount of T.D.N. consumed per pound of gain.

Feed utilization tests were conducted on four get of sire, each consisting of 10 head of steer calves. The test was conducted on the basis of controlling the caloric value of the ration and feeding according to appetite. For controlling the energy content of the gain, an attempt was made to feed to an equal degree of fatness (100).

It was concluded that body size is not fundamentally related to efficiency of production, that absolute rate of gain can be used as an index of efficiency only in comparing animals of similar (potential) size, and that relative gain and relative feed intake are in general sound indices of efficiency, providing the composition of gain is equal.

Conformation

The earlier tests are generally set up to compare the feed-lot performance of the various feeder grades. These results indicate that the "common" feeder grades usually returned more for feed eaten than the higher grade feeder cattle (14)(181)(227). The higher grading feeders also graded higher at the completion of the feeding period, but the selling price of the steers showed less variation than purchase price (22)(23)(91).

Conformation, as determined by measurements, indicates that no single measurement or group of measurements was important in predicting feeding ability (114)(201)(287). The "rangy" calves are equally superior to "low-set" calves of the same quality in ability to gain weight (128)(184).

TABLE XVII

Correlation of Animal Grade and Feed Lot Gain

Correlation	Reference
+.0001	(174)
-.021	(73)
-.04	(226)

Early in the record of performance program of research it was found that there was little or no association between type of animal and ability to grow. It has been common belief among cattlemen that they could select the faster-gaining, more efficient animals by using conformation characteristics as a criteria. A recent analysis indicates that there is no association between conformation points and ability to gain. Conformation characteristics are inherited, as well as ability to grow, but selection by visual appraisal of feeder calves for ability to gain is ineffective (231).

Score or grade of a feeder calf is no indication of his rate or efficiency of gain in the feed lot (174)(221)(269)(270)(281).

Management

An analysis was made of the gains of 422 steers from 43 different sires at the U. S. Range Livestock Experiment Station, Miles City, Montana, and at the North Montana Branch Station, Havre, Montana. The steers were started on feed immediately after weaning, varying in age from 5 to 7 months. The steers were all fed at least 252 days.

The feeding period was divided into three 84-day periods for the purpose of analysis. The gross correlation between periods 1 and 2 was 0.26, periods 1 and 3, 0.18, and periods 2 and 3, 0.39. The genetic influences for each of the three periods were 10, 54, and 84 percent of the variations in gains.

The analysis indicates that there was little environmental correlation between the three periods and that the genetic influence became greater as the feeding period progressed (172).

Although early recommendations were for an 168-day feeding period (168)(178), later studies showed that feeding periods of 100 to 150 days should be adequate (180).

Frequency distributions of the total digestible nutrients consumed and daily gains of the steers showed that on limited feeding the steers were much less variable in daily gains that on unlimited feeding. Variance analyses showed that on limited feeding the sire groups were significantly more alike than would be expected by chance, whereas on unlimited feeding the sire groups were significantly different (161). It was concluded that forced or ad libitum feeding is the best method by which differences in ability to grow may be determined.

It is commonplace in ad libitum feeding experiments that the animals receiving one diet will eat more food and grow more rapidly than those receiving another diet. The question in dispute has been whether the animals that grew faster did so because they ate more or whether they ate more because they were growing more (57). Criticism of an ad libitum feeding trial might be averted if it could be demonstrated that the diets under comparison were in fact equally palatable for the animals.

There also appears to be an advantage in feeding animals two or more times per day as comp ared to feeding the entire day's ration at one time (83)(95).

There is some apparent conflict in the experimental results comparing the relative performance of individually or group fed animals. In some of the earlier trials individually fed steers, at least for part of the feeding period, failed to make as satisfactory or economical gains as did the group fed steers (27)(284). More recent results, however, show no consistent advantage of individual or group feeding for either amount or economy of gain (16)(65)(154). It was recently noted (152) that if animals are fed higher quality hay, group fed animals will gain more than individually fed animals. When fed a low quality hay there is no difference in gain between individually and group fed animals.

There are consistent results to indicate that a concentrate to roughage ratio between 1:2 and 2:1 will promote the greatest gain and feed efficiency (72)(143)(149)(222).

If the feeding trials are conducted in a hot climate, animals with Bos Indicus breeding will sbow an advantage (233). The temperature may also affect the rate of development of at least certain tissues of the animal (195).

During hot weather, water consumption of Brahman cattle was consistently less than that of Hereford cattle (136). Cooling the drinking water to 65° resulted in less feed consumption and greater gain for those animals. Four ways to increase summer gains of beef cattle in the hot summer have been stated (133):

(a) Shades made of aluminum or hay, 10 to 12 feet above the ground with 60 square feet of shade per animal

(b) Cool drinking water will increase daily gain 0.26 to 0.44 lb.

(c) Add more concentrate to the ration, since it produces less heat increment than straight roughage

(d) Wire pens are more effective than small wooden corrals

Herefords and Brahmans exhibited a marked difference in the way they consumed feed. The Brahmans ate more slowly and not so much at one time while the Herefords gulped their grain. The Braford cattle ate more like the Herefords (134).

Bloat

There is good evidence of inherent differences between the progeny of different bulls in ability to handle large quantities of feed without digestive disturbance (130)(165), although only some types of bloat may be genetically conditioned (63). Tympanometer readings on bloated steers indicated pressures of 20 to 60 mm. Hg. In acutely bloated steers, the pressure was around 80 mm. Hg. Death is apparently caused by tissue anoxia and asphyxiation (10).

The paunch contents from steers with rumen fistulae were examined at 4-hour intervals over a 24-hour period (55). Three groups were compared:

(a) High plane of nutrition
(b) Intermediate plane
(c) Low plane

Steers were fed at 8:00 A.M., and 4:30 P.M. The water intake was observed:

(a) Low plane - consumed water for 24 hr. period at 8:00 A.M.
(b) Intermediate plane - consumed 24 hr. supply at evening feed
(c) High plane - consumed equal amounts at A.M. and P.M. feeding.

As the plane of nutrition increased the dry matter tended to disappear from the rumen more rapidly shortly after feeding than it did at each succeeding period thereafter. The passage of dry matter out of the rumen followed a pattern which appeared to bear little or no relationship to the amount of water in the rumen.

The amount of dry matter in the rumen preceding feeding was approximately the same amount as that consumed in a feeding period. This relationship was essentially the same regardless of the time interval between findings. The amount of feed in the rumen before feeding was about equal to the amount to be fed whether the amount regularly fed at one time was three pounds or twice this amount.

The net energy expense of walking (expense above standing) per unit live weight and per unit horizontal distance is independent of speed (107). It is 33 calories per 100 lbs. live weight per horizontal mile for cattle. Light exercise, equivalent to walking 3.7 miles a day on the level, increased feed consumption per unit of gain (53). To produce 100 pounds of gain, exercised steers required an average of 17 percent more concentrates, 10 percent more silage, and 10 percent more alfalfa hay than unexercised steers. Heavier walking, equivalent to walking 8.9 miles per day on the level, increased concentrate consumption 72 percent, hay 9 percent, with a decrease of 4 percent in silage.

Fattening steers and calves, fed and sheltered in the barn and having access to lots for exercise, consumed the same amount of feed and made equal gains to those fed in the open (229). Creep fed calves, when placed on fattening ration after weaning, gained .16 lb. per day less and required more feed per 100 lbs. gain (141). Animals that are even lightly infested with gastrointestinal parasites will not gain as well as treated animals (122). It has been suggested that noninfested animals are more effective in converting carotene to vitamin A (75).

Angus and Hereford calves were weaned at 90 and 180 days and fed individually until 370 days of age (98). The average gain per 28-day feeding period was much more uniform for the 90-day group. It is thus possible that an earlier evaluation of rate of gain is possible by early weaning.

Weanling rats were extrahandled by removing them from their cages and petting them for ten minutes each day. Unhandled animals were never touched during the test period. The extrahandled animals gained 122.8 grams, the unhandled 108.1 grams. There was no statistical difference in amount of feed eaten (237). The extrahandled animals exhibited much more activity and curiosity than the unhandled group. They spent more time scampering around the cages and watching other activities. The thyroids of the unhandled animals were in a more active state than those of extrahandled as indicated by the difference in percentage dose uptake of I^{131}. This increased thyroid activity on the part of the unhandled animals, whether or not it is a function of differences in anxiety level, may well be an important mediating factor in the production of the observed differences in growth and food utilization. Both groups exhibited approximately the same percentage of fat and moisture per 100 gram body weight. There were no significant differences in weights of kidneys, livers, or spleens. The unhandled animals excreted a mean of 3017 fecal pellets. Extrahandled excreted 2705 pellets. A theory to account for the effects of early handling has been postulated (29). A major change in hypothalamic functioning, involving reduction or inhibition of massive sympathetic discharge in response to an alarming stimulus and, hence, decreased ACTH output from the pituitary is suggested. Early handling would thus appear to have induced a permanent rise in the threshold for emotional reactivity.

In 1952, 7.85 percent of the livers from adult cattle slaughtered were condemned for abscesses, and 0.66 percent of the livers of all calves (139). In the adult fattened cattle examined, 37.6 percent contained lesions of rumenitis (138). Feeding barley in reasonably large amounts to cattle which are not accustomed to grain as a part of their ration caused the formation of high concentration of acid within the rumen.

Conformation Score

Animal type score or grade is a visual appraisal of the animal based on a standard which can be considered as the ideal conformation. It has been recognized for some time that the show ring is inadequate as a means of selecting animals best suited for the packer and retailer (269). In 1900, a livestock producer expressed his opinion in a letter to a trade journal (132):

"When we consider that the great bulk of the beef, pork, and mutton supply of the markets of the world is produced by the average farmer and feeder, it would seem that if these shows are maintained in the future they should be so managed that their influence for good breeding and profitable feedings should be felt by this great army of breeders and feeders.

"Let more attention be paid to thick flesh of prime quality and less attention to surplus fat. Let us learn the difference between flesh and fat, and there is nothing that will give us as profitable lessons along this line as the slaughtering and cutting up of some of the show animals. We need not expect to see the popular winners on foot make carcasses of beef that will meet with popular favor.

"With all the knowledge possessed by our best breeders and feeders, the production of the show animal is the exception and not the rule, but there is hardly a breeder or feeder who has not sufficient knowledge to produce beef, pork, and mutton of choice quality if he really desires to do so.

"When we consider the cost of beef production and the small margin feeders have had the last few years on the cattle they have fattened and sent to market, I would like to see the question of feeds and feeding discussed at these shows."

The great mass of experimental data which has been accumulated shows that scoring as a technique of evaluation of differences of animals is subject to considerable error and is probably of very doubtful value when differences between animals are small. When the population to be studied shows large differences, the scoring technique is undoubtedly the simplest way to evaluate differences in conformation (169).

Statistical studies show that the agreement between judges is relatively low, generally between .4 and .7 (49). The repeatability of a judge's scores of the same cow in different seasons was generally between .4 and .6. There were also highly significant differences between scores of age groups as well as between scores at different ages of scoring (48). There is a downward trend in the scores from calfhood until roughly the age of first lactation, after which the scores tend to increase up to about 5-1/2 years. After this, scores remain about constant until changes associated with senility begin to cause a decline.

Live animal measurements have been compared to photographic measurements (248).

Character	Repeatability: Live-Animal Measurement	Repeatability: Photographic Measurement
Body length	.546 to .898	.726 to .844
Height at withers	.888 to .906	.908 to .927
Depth of chest	.784 to .914	.807 to .908

Photographic measurements gave slightly higher estimates of repeatability.

Measurements have been used in an attempt to accurately describe a grade. The index:

$\frac{\text{round measurement x 100}}{\text{height}}$ has been shown to be highly correlated with grade (101).

$\frac{\text{height at withers}}{\text{circumference at chest}}$ has a heritability (.45) that is high enough to consider its use as an objective measure in selection (288).

Factors Affecting Conformation Grade

(a) Correlation of weight and grade = -.24 (226).

(b) Width and depth of body, thickness of finish, and shape of head were closely related to feeder grade, the correlation coefficient in all instances exceeding +.90 (114).

(c) Correlation of grade and condition = +.23 (73).

(d) Steers increased more in width during fattening than they do in length or depth of body, and least of all in height and head measurements (202).

Heritability of Animal Measurements

Measurement	Heritability	Reference
Circumference rear flank	.28	(70)
Circumference shin bone	0	(70)
Height at hooks	.75	(153)
Head width	0	(153)
Head length	.96	(153)
Width at hooks	.62	(243)
Heart girth	.36	(243)
Length of rump	0	(70)
Length of coupling	.12	(70)
Length of nose	0	(70)
Width between eyes	.38	(70)
Width of muzzle	.50	(70)
Width at chest	.04	(70)
Width at chest	.26	(243)
Width of last rib	0	(70)
Width of hip	.06	(70)
Circumference at naval	.55	(70)
Circumference of foreflank	.58	(242)
Circumference of foreflank	.26	(70)
Height at flank	.55	(70)
Depth of chest	0	(70)
Depth of chest	.20	(243)
Height floor of chest	.83	(242)
Height floor of chest	.01	(70)
Height at withers	1.00	(242)
Height at withers	.63	(70)
Height at withers	.50	(47)
Height at withers	.76	(243)
Height at withers (6 mo.)	.41	(52)
Height at withers (12 mo.)	.60	(52)

Measurement	Heritability	Reference
Width of shoulder	0	(242)
Width of shoulder	0	(70)
Length of body	0	(242)
Length of body	0	(70)
Length of body	.45	(47)
Length of body	.48	(243)

Measurement and Weight

In a comprehensive review of work on the subject, it was concluded that live weight can be estimated on the basis of heart girth alone, as well as with a combination of two to several measurements (140). It is necessary to use a straight-line equation for subgroups with moderate age intervals. Tables and regression equations have been presented (265). For steers with heart girth from 63 to 80 inches, the following formula has been used (13):

$$1.04\,[(27.5758 \times \text{heart girth in inches}) - 1049.67]$$

Record of Performance Procedures

The importance of using Record-of-Performance for selection in beef cattle has been recognized for a number of years. An early attempt was made to incorporate dimension and weight into an index for cattle (289). This index was considered as follows:

1. The specific gravity of the body as a whole = .9694
2. One pound of tissue as it occurs in the animal body occupies a volume equivalent to 475.8 cubic centimeters
3. $I = \dfrac{H^2 \times L}{W \times K}$

I = Dimension - weight index
H = Wither to ground height
L = Shoulder point to pin bone (body length)
W = Weight in pounds
K = Constant (475.8) volume of 1 pound of flesh

This plan apparently has not been tried, at least to any extent. A method for evaluating beef cattle for a register of merit has been outlined (246). The proposal consisted of a detailed plan for management and feeding of calves including standardized rations and an estimate of milk production while the calf was nursing. The following formula was proposed:

$k \times Y$

k = .065
X = Pounds of cold dressed carcass produced per 100 pounds of T.D.N.
Y = Numerical term to express carcass grade and tenderness of cooked meat.

The most significant indicators of net profit were found to be daily rate of gains and final market evaluation (283). Together they accounted for 87.3 percent of the variations in profit. Based on this information, a record of performance for beef cattle was proposed (282). The animal's final evaluation is based on daily gain from birth to 365 days and the body score taken when the animal reached 365 days of age. The two factors were to be given equal emphasis.

The early U.S.D.A. record-of-performance procedure as set up at Beltsville was as follows (17):

1. All calves to be allowed to nurse their dams on pasture with access to a grain mixture

2. All animals to be weaned at a constant weight, regardless of age

3. All animals to be slaughtered at a constant weight

4. The method of feeding for the fattening period to be individual self-feeding

5. The record-of-performance ration may vary and probably should vary with the region, using the most practical and available feeds, but it must be constant from year to year in any one series of tests

6. Body measurements considered significant as indications of type to be taken at the time the calf goes on feed and again when slaughtered

7. Carcass studies to be made of all animals including the following:

   (a) dressing percent, (b) grade of carcass, (c) color of meat (d) percent of wholesale cuts, (e) tenderness of cooked meat as determined both mechanically and by a committee, (f) percent of separable fat, lean, edible meat, bone, and waste, (g) chemical analysis of the amount of ether extract in rib cuts, protein, etc.

8. The final score would be:

   $$ROP = .05\ (E)\ (Q)$$

   where E = gain per 100 pounds of total digestible nutrients and Q = carcass grade in percent.

In comparing several methods of measuring performance in beef cattle (19), it was concluded that efficiency of gain from 500 to 900 lbs. and a quality score based on carcass grade were most important.

A more detailed procedure for gathering record-of-performance data on beef cattle has been outlined (281):

1. Calves' birth weights

2. Calves nursed by their own mothers and creep fed until they reach 450 lbs., then weaned but allowed to continue on the self-feeder

3. The feeding trial to commence at 500 lbs. and continue to the 900-lb. weight.

4. The animals' merits in body conformation to be appraised on a percentage of perfection basis, this percentage to be arrived at both by the use of good judgment of desirable body form and the aid of the equation: ROP = .05 (E) (Q)

When individual feeding is possible, a record would be kept of feed consumption between 500- and 900-lb. weights, as well as of carcass data.

These data would comprise:

1. Birth weight

2. Rate of gain from birth to 450 lbs. (the period from 450 to 500 lbs. is allowed as an adjustment period)

3. Rate of gain during the feeding period from 500 to 900 lbs. (This may be replaced with actual feed-consumption per unit of gain).

4. The animal's value for slaughtering

Actual experimental work with record-of-performance procedures in beef cattle were undertaken at a number of the state experiment stations and at the U. S. Range Livestock Experiment Station, Miles City, Montana. In general, all bulls on feeding test are fed the same ration with natural appetite as the limiting factor on the quantity of feed (160). Individual stalls (147), length of feeding period (178), and rations have been described. Detailed procedures and suggested record forms for performance testing are available (25)(26)(77)(85)(86)(94)(148)(276). Portable cattle scales for field use in ROP work have also been designed (50)(77)(257).

The use of pelleted feed for feeding trials has also received attention (217).

Percent of Ingredients Used in Pelleted Ration

Feedstuff	Percent of Ration
Alfalfa hay	66.5
Molasses	5.0
Barley, steam rolled	15.0
Oats, ground	5.375
Beet pulp, dried	3.25
Wheat bran	2.25
Soybean oil meal, 44%	1.75
Linseed meal, 32%	.35
Steamed bone meal	.175
Salt, iodized	.15
Skim milk, dried	.2
Yeast, irradiated	3 oz./ton

1. Gain and performance of animals on this pelleted ration was very satisfactory.

2. Little or no rumination was noted by the calves. When placed on normal hay after completing feed test, rumination was normal.

3. No digestive disturbances that could be attributed to pellets occurred.

Some of the advantages of completely pelleted ration:

1. Accuracy. Less weighing of feed and no sifting of feed by the calves.

2. Ease of feeding. Record keeping can be kept to a minimum and individual self-feeders are very satisfactory.

3. Increased feed intake. Calves consumed more feed when pelleted, permitting an opportunity for maximum genetic expression of growth.

Accuracy of Weights

An early study (204) indicated that the standard deviation in the accuracy of single weights of cattle may be expected to be between 6 and 12 lbs. Breed and disposition had no appreciable effect. It was recommended that 3-day weights be taken. Later studies (6)(8)(224)(225) showed that if animals are weighed at the same time each day, preferably a shrunk weight, a single-day weight was completely adequate.

In weighing steers off grass, the availability of water is a more important source of variation than availability of grass. Steers weighing from 800 lbs. to 1000 lbs. lost about one pound every 10 minutes during the first 3 to 4 hours of shrinking, whether they were held in dry lot or were being quietly driven (271). It was suggested that all lots of cattle have water equally available at all times, and shrinking cattle 10 to 15 hours before taking weights that are to be used in the final evaluation of treatment effects may increase experimental efficiency (272). If several lots are involved, they should be weighed as rapidly as possible to prevent excessive loss of fill by those being weighed last.

Weights recorded early in the day when animals are generally of a constant habit have day-to-day variations comparable to overnight fasting (127).

Rumen Physiology

Techniques for sampling, culturing, and counting bacteria in the rumen have been described (88). Bacterial slide counts of rumen contents from cattle averaged about 50 billion per gram while they were on winter rations, and averaged 96 billion when on pasture. The bacteria from animals on pasture appeared morphologically similar to those on winter rations. There was a noticeable increase in fast-growing organisms correlated with an increase in the amount of grain in the ration (87)(89).

A total of 896 strains of bacteria has been isolated from the bovine rumen (51). A direct microscopic count showed 20.2 billion bacteria per milliliter. Almost all were strict anaerobes. Many of the groups of bacteria isolated required carbonate in the culture medium before growth was obtained, and several groups did not grow well unless rumen fluid was included in the medium. Animals on a single ration had 51 different kinds of bacteria in the rumen (126).

The gases produced in the rumen are carbon dioxide and methane and small amounts of hydrogen sulfide (254). Nitrogen and a small amount of oxygen are present in rumen gas because of the entrance of air into the rumen. Different feeds apparently produce the same gases; at least the percentage composition of rumen gas from different feeds shows only slight variation.

The end-products of fermentation appear to be largely acetic and propionic acids and carbon dioxide (228). The temperature of the food mass in the rumen is a degree or two above body temperature (62). Samples of rumen content from various breeds, classes, and grades of cattle were obtained. The pH value of 473 samples averaged 6.859. No significant differences in the pH values were obtained from these various animals, and no seasonal difference could be demonstrated (220).

The composition of bovine saliva is as follows:

Specific gravity	1.008
pH	8.8
Water	99.15%
Organic matter	0.17%
Inorganic matter	0.68%
Na	0.2768%
My	0.006%
Chlorides	0.0154%
Sulphates	0.0145%
Phosphates	0.359%

No mucin or ptyalin.

About 80 percent of the food residues are excreted between 70 and 90 hours after administration (3). A diet composed of ground hay was excreted over a longer period than one of unground hay. Ground plus unground hay was excreted faster than unground alone.

Finely divided particles of food pass through the rumen more rapidly than large particles when both are fed together, but if the whole ration is ground it remains in the rumen for an abnormally long period and the fibre is less completely digested (228).

The rumen is constantly contracting in the animal at the rate of 2 or 3 per minute (254). The cow ruminates 6 to 8 hours of each 24 and each ruminating period lasts about 15 minutes (62)(254). It has been concluded that an adequate water supply readily accessible to the animal is an absolute requisite for physiologic rumination (240).

The rumen, reticulum, and omasum are devoid of glandular epithelium. The only secretory part of the ruminant stomach is the abomasum (3).

Digestibility

The expanding knowledge in the field of ruminant nutrition has shown the possibilities for effective utilization of roughages. It has been shown that a symbiotic relationship exists between the ruminant and the microorganisms in the rumen. It is now known that the efficiency with which rumen microorganisms perform their vital symbiotic processes, including cellulose digestion, is dependent upon the nutritional adequacy of the rumen environment.

Present findings indicate that the nutritive requirements of rumen microorganisms consist of four general classes of nutrients. These are (1) source of readily available energy, (2) source of nitrogen, (3) minerals, and (4) unidentified stimulatory factors.

There are some conflicting results concerning the effect of level of feeding on digestibility. It has been reported the lowest level of feeding was associated with the most complete digestibility of all nutrients (211). However, there was a progressive decrease in digestibility from the lowest to the highest ration only in the case of nitrogen-free extract, ether extract, and dry substance.

The digestibility of a single feedstuff like hay constituting the sole ration is practically unaltered either by the amount of hay fed within wide limits or by the nutritive plane of the animal (12). In an experiment involving identical twins, no influence of feeding intensity on the animal's ability to digest feed could be demonstrated (118). In a limited study with steers it was concluded that the condition of the animal appears to have a decided effect upon the digestive ability. A very low plane of nutrition depresses the coefficient of digestion (262).

Concurrent chemical and radiocalcium balance studies were carried out with 34 Hereford cattle ranging in age from 10 days to 190 months (116). The absorption and/or true digestibility values were greatest in young animals, decreased rapidly to sexual maturity, then more slowly to maturity, and again decreased in aged animals.

The maintenance requirements per 100 pounds body weight calculated from endogenous and true digestibility values ranged from 0.5 grams at 10 days to 2 grams at 6 months and remained relatively constant to maturity (116).

In a rather limited study of the relationship of feed efficiency to digestion rates of beef cattle, the data presented from one trial indicated that digestion of crude fiber was related to feed efficiency, indicating that digestion of crude fiber is possibly one of the more important factors affecting feed efficiency. In a second trial with a ration lower in crude fiber the correlation coefficient for crude fiber digestion followed a similar pattern but only approached significance. Digestion of other food nutrients did not appear to be significantly related to feed efficiency under these conditions.

Differences in rates of gain were probably not due to any large extent to individual differences in digestive powers of the animals (9).

In a preliminary trial to determine the optimum protein allowance for fattening steers for various levels of roughage intake, the following conclusions were made (150):

1. Replacing 12 percent of the concentrate mixture with soybean oil meal to increase the protein content of the ration for fattening steers did not increase the rate and economy of gain.

2. The level of roughage intake had no effect on the requirements of protein for fattening.

3. More economical gains were obtained with steers fed a constant ratio of concentrate to hay throughout the feeding period than the method of feeding a high proportion of roughage at the beginning of the period, followed by the system of gradually reducing the hay and increasing the concentrate as the feeding period progresses.

In a later report it was stated that the addition of protein to either hay and silage roughage rations or hay roughage rations did not increase the rate of gain or reduce the feed requirements of the test steers (144). The feed requirements for each 100 lbs. of gain of the steers fed the alfalfa hay with silage decreased from 1294 lbs. for the 1:3 ratio to 1064 lbs. for the 1:1 ratio of concentrate to roughage. Those steers fed the alfalfa hay without silage required less total feed when fed a 1:1 ratio than those steers fed the 1:3 ratio of concentrate to roughage, while the steers fed the 1:3 ratio made the cheaper gains.

A feeding trial using pelleted feed has proved very satisfactory and the calves actually consumed more of the feed in the pelleted form (217).

Variations in the daily gain of steers resulted from different levels of carotene in the ration (145).

Excess vitamin A administration depresses the effect of thyroxine and thus modifies the activity level of the thyroid. Vitamin A in heavy doses lowers the basal metabolism by 10 percent (238). In one experiment (56) aureomycin and potassium penicillin G were shown to inhibit thyroid activity in the rat as measured by the uptake of I^{131} and the weight of the thyroid gland. A later report (196) states that neither penicillin nor aureomycin altered the size of the thyroids or the uptake of I^{131} in the rat or in chickens.

The feeding of some commercial phenothiazine preparations resulted in reduced thyroid uptake of I^{131} in poultry, sheep, swine, cattle, and burros, and may be indicative of an induced hypothyroidism (258).

The thyroid was excised from steers and during the first 4 to 6 postrecovery weeks the rate of gain was consistently accelerated (ave. 2.6 lbs.). After the sixth week the rate of gain was reduced (ave. 2.0 lbs.)(54).

In a comparison of the digestibility of certain feeds for cattle and sheep it was concluded that digestibility data to be used for cattle should be obtained from cattle (59).

The determination of lignin has been used to establish nutrient intake of animals (74)(80)(260). Sampling procedures and methods have been established and have proved satisfactory (119)(260). The chromogen-chromium oxide method for determining dry matter intake has been applied to pasture studies (32) and to record-of-performance animals (216). The digestion coefficients calculated by the ratio technique are in good agreement with those determined by total fecal collection for ether extract and fiber (216).

In an early study with rats (212) it was determined that heritable factors were important in determining the efficiency of food utilization. In the rat, the female consumes much more dry matter per unit of gain per unit of body weight than does the male.

In cattle, there is an indication that rate of gain is a better measure of efficiency than the ratio of gain to feed consumption unless adjustment is made for differences in weight or constant end weights are used (99). The high correlation between rate and efficiency of gain is reduced in time-constant populations and this high correlation is applicable only between animals of the same potential size (163). In time-constant feeding tests, selections should be made for rate of gain rather than gross efficiency. The correlation between rate of gain and efficiency of feed utilization has been reported as +0.49 (162)(163) for Hereford cattle, and +0.48 for Hereford and +0.87 for Shorthorns (236).

A method of determining relative feed efficiency by measuring serum protein bound iodine levels has been reported (192). For Hereford bulls the correlation of P.B.I. with efficiency was +0.84.

The rate of gains of two-year-old steers depends upon the amount of feed consumed. However, the amount of feed consumed between one-third and full feed apparently has no effect upon the economy of gains as measured by the consumption of feed of total dry substance, of digestible dry substance, and of net energy per pound of gain. Steers which have been kept on a low plane of nutrition (maintenance) for a considerable time make more economical gains when put on a full-feed ration than steers which have been on full feed for some time. However, steers receiving more than a maintenance but less than a full-feed ration make no more economical gains when put on full feed than steers which have already been on full feed (215).

Growth per feed unit decreases with age for different planes of nutrition (117). Calves require less feed per 100 lbs. gain than yearlings or two-year-olds (67).

Record of Performance Results

The United States Range Livestock Experiment Station, Miles City, Montana, in cooperation with the Montana Agricultural Experiment Station, undertook in 1936 to produce an inbred line of Hereford cattle basing selection on economic performance. The foundation sires of Line 1 were purchased from a Colorado breeder and the cows were Station cows that trace directly to five sires previously used in the herd. The original breeding program called for half-brother-sister matings as far as possible, but this plan could not be strictly adhered to.

Inbreeding has increased rather slowly, and the inbreeding of the 1948 calves reached only 15.95 percent.

Improvement in the line for rate of gain at 15 months was 0.16 lb. and for weight at 15 months was 66 lbs. (170)(171).

Since 1936, a number of lines have been started. Careful production records are kept and selection of replacement animals for these lines has been primarily on performance.

One of the principal projects conducted at the Station is to determine whether ability to make economical gains can be appraised by observation of the live animal.

An analysis of data from 181 steers fed out under record-of-performance methods showed that there were apparent hereditary differences between the progeny of different sires in ability to gain, in weight for age, and in conformation characteristics. Table XVIII gives the results of feeding tests during 1948-49 of 8 steers from each of 13 bulls showing the variation that may be expected during most years (231).

Between the best and the poorest progeny groups there was a difference of 119 pounds in weaning weight, and 211 pounds at the end of the feeding period. In net returns above feed and marketing cost there was $45 per head difference between the progeny of the best and poorest bull. On the 8 calves, therefore, the best bull returned $360 more than the poorest bull. Such differences are by no means exceptional, as shown by performance testing.

Early in the record-of-performance program of research it was found that there was little or no association between type of animal and ability to grow. It has been common belief among cattlemen that they could select the faster-gaining, more efficient animals by using conformation characteristics as a criteria. A recent analysis indicates that there is no association between conformation points and ability to gain. Conformation characteristics are inherited, as well as ability to grow, but selection by visual appraisal of feeder calves for ability to gain is ineffective.

TABLE XVIII

Average Results of Record-of-Performance Feeding of Eight Steers from Each of 13 Bulls in 1948-49

Bull Number	Sire Number	Birth Weight (pounds)	Weaning Weight (pounds)	Final Weight (pounds)	Daily Gain (pounds)	Slaughter Grade	Returns above Feed Costs (dollars)
T1	166	83	401	934	2.12	G-	113
T2	167	82	394	940	2.17	G+	116
T3	168	81	433	1,004	2.27	G+	123
T4	169	79	399	965	2.25	G	126
T5	170	82	397	966	2.26	G+	121
T6	171	73	374	893	2.06	G	112
T7	173	81	493	1,079	2.32	G+	148
T8	174	82	460	1,040	2.32	G	136
T9	177	92	464	1,054	2.34	G+	137
T10	178	81	422	981	2.22	G+	126
T11	182	84	418	998	2.30	G	126
T12	189	80	438	959	2.07	G	116
T13	188	83	392	868	1.89	G-	103

Detailed results of the performance testing work at the Miles City Station have been reported (60). In a test at the Ohio Station, three lots of yearling steers produced at Miles City were compared with check lots of commercial feeder steers obtained at the Kansas City and St. Paul markets. They were fed for 196 days and checked for rate of gain, efficiency of gain, dressing percentage, and carcass grade (92). The Miles City steers outgained the check lots 9 percent and were 8.5 percent more efficient. The check lots outdressed the Miles City animals 1.5 percent, but did not yield carcasses that graded as high as Miles City steers.

Studies of progeny steer groups at the Montana Agricultural Experiment Station at Bozeman showed that for the five years 1946-50 there was a difference in the net return above feed cost of $30 to $40 per steer between the progeny of the best and the poorest performing bulls tested (277). Feeders in the midwest and elsewhere are showing preference, expressed in premium prices, for steers sired by rapid and efficient gainers (275).

Significant differences for gaining ability have been noted for progeny of different sires and also between herds (105)(197)(221)(223). There also are indications that, in gains after weaning, some sires apparently produce better gaining heifers than steers or better-gaining steers than heifers. If this is true, superiority should be demonstrated for both sexes in evaluating a sire (179).

To determine whether the relative performance of different sires will be similar when bred to different cow herds and to herds which are subjected to different environmental conditions and management procedures, steer progenies of 11 bulls were compared. Bulls were used at two different stations, Havre and Miles City (285).

(a) There was no significant difference in birth weights between calves sired at the different stations.

(b) Sires producing fast-gaining (birth to weaning) calves at one station tended to do the same at the other station.

(c) Some of the sire groups made fast feed-lot gains at one station and slow gains at the other. Similar results were obtained for efficiency of gain.

A record-of-performance feeding trial for 102 Shorthorn bulls fed 122 days was conducted by the Shorthorn association. At the completion of the trial the bulls were sold at auction. The results of the trial and sale were analyzed to determine the effect of performance on sale value (142).

TABLE XIX

Average, Standard Deviation, and Range of the Characteristics Studied in Range Bull Performance Test

Column		1	2	3	4
			Standard	Range	
Line	Character	Average	Deviation	Top	Bottom
1.	Age (end of test--days)	485	45.1	600	397
2.	Initial weight (lbs.)	772	95.7	998	548
3.	Type 1 (beginning)	8.9	2.1	13	4
4.	Condition 1 (beginning)	7.4	1.4	11	4
5.	Gain (lbs.)	241	60.6	450	103
6.	Final weight (lbs.)	1013	109.9	1285	745
7.	Type 2 (end)	8.6	2.1	13	3
8.	Condition 2 (end)	8.2	1.6	13	3
9.	Price (dollars)	516.73	280.46	1500	205

TABLE XX

Correlation Coefficients of Characteristics Studied in Range Bull Performance Test

Column		1	2	3	4	5	6	7	8
Line		Initial Weight	Type 1	Cond. 1	Total Gain	Final Weight	Type 2	Cond. 2	Price
1.	Age (in weeks)	.53	.05	.08	.11	.52	.11	.20	.23
2.	Initial weight		.55	.63	-.07	.83	.56	.58	.41
3.	Type 1 (beginning)			.83	-.27	.33	.70	.54	.33
4.	Condition 1 (beginning)				-.30	.38	.70	.63	.40
5.	Total gain					.49	.09	.16	.37
6.	Final weight						.54	.59	.62
7.	Type 2 (end)							.81	.62
8.	Condition 2 (end)								.63

TABLE XXI

Regression Coefficients of Characteristics Studied in Range Bull Performance Test

Column	1	2	3	4	5	6	7	8
Line	Initial Weight	Type 1	Cond. 1	Total Gain	Final Weight	Type 2	Cond. 2	Price
1. Age (in weeks)	7.93	.02	.02	1.03	8.96	.04	.05	9.89
2. Initial weight		.01	.01	-.04	.96	.01	.01	1.20
3. Type 1 (beginning)			.56	-7.58	7.05	.70	.40	43.05
4. Condition 1 (beginning)				12.67	29.18	1.04	.69	78.31
5. Total gain					.89	.003	.004	1.69
6. Final weight						.01	.008	1.58
7. Type 2 (end)							.60	81.79
8. Condition 2 (end)								111.52

TABLE XXII

Partial Regression Coefficients of Some of the Characteristics Studied in Range Bull Performance Test

Column		1	2	3
		Variables		Regression
Line	Independent	Dependent	Held Constant	Coefficients
1.	Gain	Type 1	Condition 1	-1.46 lbs.
2.	Gain	Condition 1	Type 1	-10.88 lbs.
3.	Price	Type 2	Gain	$78.06
4.	Price	Type 2	Condition 2	42.76
5.	Price	Condition 2	Type 2	64.69
6.	Price	Condition 2	Gain	103.79
7.	Price	Gain	Condition 2	1.26
8.	Price	Gain	Type 2	1.44
9.	Price	Gain	Type 2 & Condition 2	1.33
10.	Price	Final weight	Type 2 & Condition 2	.91
11.	Price	Type 2	Condition 2 & gain	47.10
12.	Price	Condition 2	Type 2 and gain	51.84

TABLE XXIII

The following table was prepared to aid in determining whether observed differences in progeny groups are due to chance or are real differences (166)

This table is based on the expected error within a year and no effort should be made to apply these figures to animals raised in different years. The table should be useful in comparing the progeny of any two bulls. It should be understood, however, that in cases where statistical significance is not demonstrated, the sire whose progeny were superior in weights or gains should be selected.

NECESSARY DIFFERENCES IN PERFORMANCE FACTORS TO BE CONSIDERED SIGNIFICANT ($P < .05$) FOR VARIOUS NUMBERS OF ANIMALS IN EACH SIRE GROUP

Number of Animals in Each Sire Group	Weaning Weight lbs.	Daily Gain in Feed lot lbs.	Efficiency of Gain in Feed lot lbs.	Slaughter Steer Grade Score*	Carcass Grade Score*	Dressing Percent (Numerical Difference)	Weight of Heifers at 18 Months of Age lbs.	Weight of Heifers at 30 Months of Age lbs.
2	67	0.31	2.74	6.78	5.46	2.73	102	138
3	54	.25	2.24	5.54	4.46	2.23	83	113
4	47	.22	1.94	4.79	3.86	1.93	76	98
5	42	.20	1.73	4.29	3.45	1.73	65	87
6	38	.18	1.58	3.91	3.15	1.58	59	80
7	36	.17	1.47	3.61	2.92	1.46	55	74
8	33	.15	1.37	3.39	2.73	1,37	51	69
9	31	.15	1.29	3.20	2.57	1.29	48	65
10	30	.14	1.23	3.03	2.44	1.22	46	62
12	27	.13	1.12	2.77	2.23	1.11	42	56
14	25	.12	1.04	2.56	2.06	1.03	39	52
16	24	.11	.97	2.40	1.93	.97	36	49
18	22	.10	.91	2.26	1.82	.91	34	46
20	21	.10	.87	2.14	1.73	.86	32	44
30	17	.08	.71	1.75	1.41	.71	26	36

* A score of 6 is required for each full grade.

Heritability Estimates

Item	Heritability	Reference
Weaning score	31	(174)
Gain on test	70	(174)
Gain on test (males)	26	(226)
Gain on test (females)	30	(226)
Weaning score	26	(235)
Yearling score	63	(235)
Yearling gain	24	(235)
Weaning score	53	(177)
Slaughter steer grade	63	(177)
Efficiency of gain	17	(70)
Rate of gain	44	(70)
Rate of gain	54	(266)
Rate of gain	60	(247)
Final weight on test	84	(247)
Efficiency of gain	22	(247)

Slaughter grade	42	(247)
15-month weight	86	(173)
Gain on test	65	(173)
Weaning score	28	(173)
Slaughter steer grade	45	(173)
Final feed-lot weight	81	(176)
Gain on test	99	(176)
Efficiency of gain	75	(176)
Gain on test	59	(242)
Steer slaughter grade	38	(242)
Efficiency of gain	38	(242)
Gain on test	63	(187)
Efficiency of gain	26	(187)
Days, birth to 900 lbs.	4	(187)

A summary of "heritability estimates" obtained in uniformity trials with monozygotic bovine twins (255).

Character	Heritability	No. of MZ Twin Pairs
Grazing Habits		
1. Grazing time	98	6
2. Loafing time	85	6
3. Lying-down time	64	6
4. Distance covered	74	6
5. Number of defecations	88	6
6. Number of urinations	47	6
7. Number of drinks (water)	84	6
Size and Growth		
1. Body weight	95	39
2. Absolute growth rate	93	10
3. Relative growth rate	90	10
4. Height at withers	91	20
Blood Characteristics		
1. Erythrocyte count	80	12
2. Erythrocyte volume	89	10
3. Hemoglobin content	93	10
4. Erythrocyte fragility	94	25
5. Serum clacium	55	19
6. Serum magnesium	95	19
7. Phosphorus (whole blood)	94	19
8. Sugar (whole blood)	17	18
9. Acetone bodies (whole blood)	46	19
Heat Tolerance		
1. Body temperature	97	7
2. Respiration rate	94	7
Food Intake and Fecal Excretion		
1. Food intake	89	12
2. Fecal nitrogen	95	12
3. Dry matter content of feces	82	12

Correlations:

Gain in Feed lot with:

Item	Correlation	Reference
Weaning score	+.0001	(174)
Weaning score	-.04	(226)
Weaning score	+.025	(166)
Weaning score	-.012	(184)
Weaning score	-.27	(142)
Weaning score	-.021	(73)
Initial weight	+.06	(226)
Initial weight	0	(151)
Initial weight	+.088	(166)
Initial weight	+.28	(184)
Initial weight	-.07	(142)
Birth weight	+.19*	(287)
Birth weight	+.28	(69)
Birth weight	+.43*	(286)
Birth weight	+.47**	(166)
Gain, birth to weaning	+.12	(270)
Gain, birth to weaning	-.04	(69)
Gain, birth to weaning	+.09	(166)
Gain, birth to weaning	0	(68)
Height at withers	+.09	(287)
Height floor of chest	+.12	(287)
Depth of chest	-.16*	(287)
Width between eyes	-.18*	(287)
Width at chest	-.09	(287)
Height at withers	+.13	(236)
Chest width	-.02	(236)
Chest depth	+.33	(236)
Heart girth	+.06	(236)
Gain in height	-.29	(236)
Head length	+.39	(203)
Body length	+.33	(203)
Chest depth	+.31	(203)
Width at eyes	+.29	(203)
Height at withers	+.35	(203)
Height at hip	+.36	(203)
Flank girth	+.41	(203)
Chest width	+.35	(203)
Width at rear flank	+.08	(245)
Circumference at rear flank	+.22	(245)
Height at shoulder	+.06	(245)
Height at rear flank	+.27	(245)
Width of loin	+.11	(245)
Circumference of chest	+.24	(245)
Chest depth	+.13	(245)
Height to floor of chest	+.08	(245)
Length of head	+.18	(245)
Width of shoulders	+.14	(245)

Miscellaneous:

Riboflavin intake	0	(30)
Carcass grade	+.08	(30)
Dressing percentage	-.09	(30)

Item	Correlation	Reference
Yearling grade	-.01	(73)
Efficiency of gain	+.47*	(286)
Weaning weight	+.23*	(286)
P.B.I.	-.14	(192)
Initial condition score	-.30	(142)
Final type score	+.09	(142)
Final condition score	+.16	(142)
S.O.I. (Bulls)	-.61	(108)
S.O.I. (Heifers)	.43	(108)
Heartbeat (Hereford heifers)	.47	(274)
Heartbeat (Angus heifers)	.13	(274)
Heartbeat (Hereford bulls)	.57	(274)
Heartbeat (Angus bulls)	.76	(274)
Carcass grade	+.37	(114)
Gain on summer range	-.20	(151)
Fall gain	+.05	(151)
Second winter gain	+.24	(151)
Yearling gain	+.17	(185)
Yearling weight	+.25	(185)
Yearling grade	-.01	(73)
Yearling gain	+.17	(73)
Summer gain	+.22	(78)
Blood urea	-.55	(61)
Non-protein nitrogen	-.02	(61)
Creatine	-.22	(61)
Creatinine	-.28	(61)
Glucose	-.43	(61)
Dressing percentage	-.32**	(256)
Percent round	+.34**	(256)
Percent loin	+.36**	(256)
Slaughter grade	+.49*	(286)
Carcass grade	+.43*	(286)
Area of eye muscle	+.36*	(286)
Thickness of fat	+.07	(286)
Dressing percentage	-.01	(286)
Length of body	+.64*	(286)
Length of leg	+.56*	(286)
Length of body	+.30*	(250)
Depth of chest	+.23	(250)
Height at withers	-.38*	(250)
Net return	+.82*	(250)
Feeder grade	-.10	(250)
Efficiency of Gain with:		
Rate of gain	+.49	(162)(163)
Percent forequarter	-.71**	(256)
Birth weight	+.13	(287)
Rate of gain	+.84**	(287)
Carcass grade	+.02	(287)
Dressing percentage	-.24**	(287)
Height at withers	+.01	(287)
Height at floor of chest	+.09	(287)
Depth of chest	-.19*	(287)
Width between eyes	-.10	(287)
Width at chest	-.12	(287)

Item	Correlation	Reference
Birth weight	+.152	(166)
Weaning weight	-.510**	(166)
Gain, birth to weaning	-.412**	(166)
Weaning score	-.284**	(166)
Rate of gain	+.527**	(166)
P.B.I.	+.84**	(192)
Initial heart girth (steers)	+.15	(236)
Initial height (steers)	+.15	(236)
Initial score (steers)	-.04	(236)
Rate of gain (steers)	+.69**	(236)
Initial heart girth (heifers)	-.20	(236)
Initial chest depth (heifers)	-.33**	(236)
Initial score (heifers)	+.20	(236)
Rate of gain (heifers)	+.51**	(236)
Height at withers	-.37*	(20)
Length of body	-.43*	(20)
Width of shoulder	+.45	(20)
S.O.I. (bulls)	-.72	(108)
Rate of gain (bulls)	+.43	(108)
S.O.I. (heifers)	+.03	(108)
Rate of gain (heifers)	0.06	(108)
Birth weight	+.12*	(286)
Weaning weight	-.29*	(286)
Slaughter grade	+.15*	(286)
Carcass grade	+.03	(286)
Area of eye muscle	+.07	(286)
Thickness of fat	-.03	(286)
Dressing percentage	-.23*	(286)
Length of body	+.06	(286)
Length of leg	+.06	(286)

Observations

(a) There is a possible negative correlation between milk production of dam and gain in the feed lot (174).

(b) Calves heavier at birth had a tendency to reach weaning weight and final weight of 900 lbs. at an earlier age than lighter calves (187).

(c) Steers shorter in height and in length of body and smaller in circumference of foreflank were slightly superior in gain and efficiency (187).

(d) Birth weight was positively associated with gain in the feed lot (68).

(e) The growth rate of steers on the range was positively correlated with their gain in the feed lot. In general, growth on the range at different periods was also positively correlated. This relationship can be obscured or even reversed by variable external influences (185).

(f) Blood glucose increased as body weight increased from 500 to 800 lbs. (205).

(g) Blood amino acid nitrogen varied between breeds and between sexes, with the faster-gaining groups showing lower blood levels (205).

(h) There is a correlation of +.80 for daily gain and sale value with net profit (280).

(i) In a survey of commercial operations, larger rates of gain per day than usual were associated with lower costs per pound and higher profits (124).

(j) Although rectal temperatures have a significance relative to growth rate, they have no value as indicators of rate of g rowth in individual selection (273).

(k) Animals with a greater proportion of forequarter are less efficient in feed utilization (256).

(l) The gaining ability of light red and dark red Herefords shows no significant difference (264).

(m) The genes which control growth at one period probably are the same, or include a portion of the same, genes which influence growth at a later period (235).

(n) To determine whether the relative performance of different sires will be similar when bred to different cow herds and to herds which are subjected to different environmental conditions and management procedures, steer progenies of 11 bulls were compared. The bulls were used at Havre and at Miles City.

There was no significant difference in birth weights between calves used at the different stations. Sires producing fast-gaining (birth to weaning) calves at one station tended to do the same at the other station.

Some of the sire groups made rapid feed-lot gains at one station and slow gains at the other. Similar results were obtained for efficiency of gain (285).

(o) A steer with a small head, narrow body, and small body circumference would have a better efficiency and daily gain when all steers were measured at 900 lbs. than one with a larger head, wider body, and larger body circumference (287).

(p) Factors governing growth in the prenatal period are, in part, the same as those which govern growth in the postnatal period (166).

(q) Cattle which are the "good doers" on the range were also the ones which did best in the feed lot (184).

(r) Steer calves were test fed for a five-month period, pastured during the summer, and again put on a test feed for five months. Data as shown indicate no relationship between relative performance of the progeny groups during the two test periods (1).

(s) In studying the relationship of serum protein bound iodine levels to rates of gain in beef cattle there appears to be an optimum level of P.B.I. Animals whose P.B.I. deviated from this optimum level had lower rates of gain (192).

(t) Animal measurements and scores prior to the time they went on feed test were not indicative of their ability to gain rapidly or efficiently (236).

(u) More efficient heifers tended to be more shallow-chested and often more narrow-chested. (236).

(v) Small but positive correlations were found for the yield of the preferred cuts with rate and efficiency of gain (236).

(w) In Hereford and Angus bulls, the serum alkaline phosphatase level appears to be negatively correlated with factors affecting rate of gain, efficiency of feed utilization, and feed intake (193).

(x) The optimum range of P.B.I. appears to be between 5.0 and 6.8 mg. of P.B.I. per 100 ml. serum (251). Because of the interrelationship of environment and a number of heritable factors, some animals with P.B.I. levels within the "optimum" range may give a relatively poor response in the feed lot.

(y) Thirteen body measurements were correlated with rate of gain and dressing percentage. No single measurement or group appeared important (201).

(z) Correlations between measurements of feeder steers and subsequent gains, dressing percentages, and values of the dressed beef, are low. Maximum gains are associated with a long body, tall at the withers, with a large paunch girth but small flank girth, and narrow at the loin (203).

(aa) No score card or standard based on conformation could ever be so accurate that the future performance of individual steers could be predicted from it with but few mistakes. Form and function in these respects are not closely enough correlated (203).

(bb) Steers of many shapes will gain well, and steers which gain the same way may be of many different shapes (203).

(cc) No correlations of serum organic iodine with rate and efficiency of gain were significant. There may be "optimum" levels of S.O.I. (108).

(dd) Heart ratés differed significantly between sexes and between individuals within sexes. No significant breed differences were noted. The relationship of heart rate to rate of gain is significant for all groups (274).

(ee) Higher grading carcasses were associated with more rapid gains in the feed lot when equal total gains were made (114).

(ff) Width and depth of body, thickness of finish, shape of head, and feeder cattle grade were not reliable indices of the relative rates at which animals gained in the feed lot (114).

Blood Values

In a study of the influence of temperature on blood composition of cattle (24), the environmental temperature was held constant one to two weeks before changing to another temperature. The following results were reported:

1. No obvious changes occurred between 0° and 65° F, except possibly an increase in the glucose level at lower temperatures.

2. On raising the temperature from 65° to 100° F., creatinine increased 100 percent; carbon dioxide-combining capacity, ascorbic acid, and cholesterol were all reduced to less than half the level at 50° F.

3. No apparent disturbances in water, electrolyte and colloid concentration on increasing environmental temperature from 65° to 100° F., occurred.

4. The trends in plasma protein bound iodine with changing temperature were too uncertain to permit interpretations in their bearing on thyroid activity.

5. There were no striking blood composition differences between Brahman and British cows in their response to changing temperature.

A variable excretion of creatine has been reported for steers (71). The daily excretion of creatinine nitrogen by beef steers is relatively constant and is unaffected by changes in protein content of the ration or by the addition of urea to the ration. There also appears to be an individual variation in the amount of creatinine excreted by steers of similar breed, age, and body weight.

The creatinine coefficient of two-year-old Hereford steers ingesting from 54 to 124 gm. of nitrogen daily varied from 7.80 to 12.48 with an average of 11.18.

Blood values of beef calves showed the following (61):

	Mg. Percent
Urea	11.98
Non-protein nitrogen	37.06
Creatine	2.20
Creatinine	1.32
Glucose	68.2

A study with identical twins showed a high intrapair similarity in calcium and phosphorus content of milk and blood (28). Blood calcium did not prove to be of value as a measure of calcium intake, but inorganic phosphorus in the blood plasma does appear to be closely related to phosphorus intake (182). Inorganic phosphorus levels of 3 to 4.5 milligrams per 100 cc. of blood plasma may be optimum for mature range cows in New Mexico.

The growth and general appearance of heifer calves and heifers on the range were not improved by feeding a trace mineral mixture which included iron, cobalt, copper, iodine, and manganese (218). Blood values for plasma phosphorus and hemoglobin were not significantly changed by mineral supplement.

	Yearling Heifers	Weanling Heifers
Phosphorus, mg./100 ml. plasma	3.89-7.22	4.12-7.84
Hemoglobin, gm./100 ml. plasma	10.0-13.2	9.8-11.4

A report has been made on the relationship of age of bulls to blood glutathione levels (232):

Age (Mo.)	Reduced	(Glutathione (mgm. %) Oxidized	Total
18 - 21	28.10	5.74	33.81
21 - 24	30.71	8.40	39.11
24 - 27	34.93		
27 - 30	34.90		
30 - 33	41.51	6.34	47.11

Diet, within limits, did not influence the concentration of glutathione in the bulls' blood.

Reduced glutathione of blood was determined in Hereford, Angus, and Brahman cattle, 9-13 months of age (194).

Sex	Breed	Glutathione, mg./100 ml. Blood Ave.	Range
Bulls	B	31.7	28 - 37
	H	19.7	17 - 24
	A	27.6	22 - 53
Steers	H	26.8	18 - 30
	A	35.4	25 - 76
Heifers	H	23.7	15 - 30
	A	35.4	20 - 69
	B	34.1	24 - 57

The average level of glutathione is significantly lower in Hereford than in Angus or Brahman. The heritability of glutathione level in young Hereford cattle is 86.

The tyrosine content of mixed bovine serum proteins has been determined (90). One mg. of tyrosine is contained in 18.78 mg. of total protein. A linear relationship exists between the serum protein concentration and the serum specific gravity, provided that the latter falls within the range 1.0220 to 1.0365. Within these limits, P = 362.0 (G-1.0220).

Studies have been reported on the haematology of normal healthy calves from birth to one year of age (97).

a. Coagulation time: 2 to 11 minutes. It appears slower between 20th and 35th weeks than before and after this time.

b. Blood sedimentation rate: 1.0 mm. to 7.0 mm.

c. Packed cell volume: Corpuscular value from 18.0 mm. to 61.0 mm., although most of the animals had values of 30.0 mm. to 50.0 mm.

d. Haemoglobin concentration: 4.60 to 16.05 grams per 100 ml. of blood. Majority between 9.0 and 14.5 grams per 100 ml.

e. Erythrocyte count: Influenced by age of animal. High counts were obtained during the first weeks of life.

Age	Ave. (Millions per C. mm.)
Birth	7.4
1 week	7.5
8-12 weeks	8.1
4-6 months	7.8
12 months	6.9

f. Platelet count: 150,000 to 525,000 per C. mm.
g. Leucocyte count: Common range is 6,500 to 11,500 per C. mm. of blood.
h. Neutrophil leucocytes: Varied from 6 to 64 percent; average 25 percent.
i. Lymphocytes: Ranged between 34-85 percent.
j. Monocytes: Common range 12-14 microns. Percentage from 0 to 12 percent; average 3.6 percent.
k. Eosinophil leucocytes: Size ranged from 8 to 15 microns. Percentage varied from 0 to 15 percent.
l. Basophil leucocytes: None observed.

The practice of developing show bulls on nurse cows frequently results in a syndrome known to the show man as "show-founder" (267). It develops progressively through a chain of symptoms including laziness, stiffness, lameness, misshapen bones, enlarged joints, eroded articulating surfaces of bone, and often sterility. A study of the hemocytology of bulls developed on nurse cows showed that with the exception of monocytes, the white blood cells of the bulls did not seem to be affected by season or age of animal. It was concluded that milk feeding resulted in some sort of stimulus to the lymphatic rather than the reticuloendothelial system.

Distribution of white blood cells for normal animals (267).

	Percent
Total Neutrophils	19.66
Arneth class I	1.55
Arneth class II	5.35
Arneth class III	9.29
Arneth class IV	3.62
Arneth class V	0.86
Total Lymphocytes	75.31
Young	38.73
Mature	36.58
Monocytes	1.98
Eosinophils	2.32
Basophils	0.14
Atypical forms	0.59

In a study of Indian cattle (146) the red cells, white cells, cell volume, sugar, hemoglobin, iron, total cholesterol, calcium, inorganic phosphorus, magnesium, nonprotein nitrogen, and the protein fractions were decreased in protein-deficient animals

A number of standard values in blood have been compiled for beef cattle (2).

			Value	Range
1.	Specific gravity			
	Young female	Blood	1.053	1.046 - 1.061
	Adult female	Blood	1.052	1.046 - 1.058
	Adule male	R.B.C.	1.084	1.079 - 1.090
	Adult male	Plasma	1.029	1.026 - 1.033
2.	Freezing point depression (°C)	Serum	-0.585	
3.	Erythrocyte sedimentation rate, mm./hr.		1.17	1 - 1.8
4.	Blood platelet count, thousands/mm. blood			
	Adult		684	542 - 975
	Calf		490	
5.	Packed R.B.C. volume, ml/100 ml. blood		40	33 - 47
6.	Blood hemoglobin concentration, gm./100 ml.blood		11.5	8.7 - 14.5
7.	R.B.C. hemoglobin concentration,gm./100 ml.blood		29	
8.	Erythrocyte diameters (dry)		5.9	
9.	Blood water, gm./100 ml.	Blood	85	
		R.B.C.	64	
		Serum	91	

			Value	Range
10.	Blood solids, gm./100 ml.	Blood	20	
		R.B.C.	44	
		Serum	9	
11.	Blood glucose, mg./100 ml.			
	Calf	R.B.C.	48	
	Calf	Serum	118	
	Adult	Blood	46	36 - 57
	Adult	R.B.C.	15	
	Adult	Serum	85	
12.	Adenosine triphosphate, mg./100 ml.	R.B.C.	27	
13.	Blood lipids, mg./100 ml.			
	Total	Plasma	348	185 - 511
	Neutral fat	Plasma	105	0 - 230
	Phospholipid	Plasma	84	17 - 151
	Phospholipid	Serum	80	
	Lecithin	Serum	54	
	Cephalin	Serum	3	
	Sphingomyelin	Serum	22	
	Cholesterol	Plasma	110	8 - 212
	Cholesterol, free	Plasma	37	0 - 85
	Cholesterol, esterified	Plasma	73	25 - 121
	Cholesteryl, esters	Plasma	123	42 - 204
	Fatty acids, total	Plasma	202	26 - 378
14.	Plasma Proteins, gm./100 ml.			
	Total		8.32	7.4 - 10.2
	Fibrinogen		0.72	
	Serum protein		7.60	
	Albumin		3.63	
	Globulin		3.97	
15.	Blood free amino acids, mg./100 ml.			
	Tryptophan	Plasma	1.1	0.8 - 1.2
16.	Blood phosphorus inorganic, mg./100 ml.	Blood	5.8	4.9 - 7.2
17.	Blood phosphorus, organic acid-soluble, mg./100 ml.	Blood	3.6	
		R.B.C.	9.1	
18.	Blood adenosine triphosphate phosphorus, mg./100 ml.	Blood	2.1	
		R.B.C.	5.1	
19.	Blood diphosphoglycerate phosphorus, mg./100 ml.	Blood (less	0.3	
		R.B.C. than)	0.6	
20.	Blood nucleotid phosphorus, mg./100 ml.	Blood	0.8	
		R.B.C.	2.0	
21.	Blood sulphur, mg./100 ml.			
	Inorganic	R.B.C.	1.45	
	Conjugated	R.B.C.	0.21	

			Value
22.	Blood sulphur compounds, sulphur compounds/100 ml.		
	Glutathione total	Blood	46
		R.B.C.	181
		Plasma	0.0
	Glutathione reduced	Blood	40
		R.B.C.	157
		Plasma	0.0
	Glutathione oxidized	Blood	6
		R.B.C.	24
		Plasma	0.0

		100 ml. Blood		100 ml. Plasma	
		Value	Range	Value	Range
23.	Blood vitamins				
	A as carotenal	14 µg.	6 - 18 µg.	24 µg.	10 - 30 µg.
	A as carotene	40 µg.	25 - 950 µg.	70 µg.	50 - 2000 µg.
	Ascorbic acid	0.5 mg.	0.2 - 1.5 mg.	0.5 mg.	0.2 - 1.5 mg.
	B_{12}	0.05 µg.	0.04 - 0.05 µg.		
	Choline, total		11 - 31 mg.	16.5 mg.	
	Choline, free			4 mg.	
	D^3 as calciferol			6.8 µg.	
	E as tocopherol			0.40 mg.	0.20 - 0.50 mg.
	Nicotinic acid	0.3 mg.			
	Pteroylglutamic acid				
	Total		2.1 - 3.0 µg.		1.8 - 2.2 µg.
	Free	0.15 µg.	0.06 - 0.45 µg.	0.05 µg.	
	Riboflavin	45 µg.	40 - 50 µg.		
	Thiamine	8 µg.	5 - 11 µg.		
24.	Blood hormones				
	Estrogen as estradiol	0.3 µg.		0.25 µg.	

			Enzyme Activity per 100 ml.	
			Value	Range
25.	Blood enzyme activity			
	Carbonic anhydrase	R.B.C.		80,000 - 140,000
	Catalase	Blood	202,800	81,600 - 469,200
	Cholinesterase (substrate - acetylcholine)	Serum	45	
	Cholinesterase (substrate - acetyl-betamethylcholine)	R.B.C.	211	
	Cholinesterase (substrate - benzoylocholine)	R.B.C.	Trace	
		Plasma	Trace	

			Value	Range
26.	Blood coenzymes, µg./100 ml.			
	Cocarboxylase (as bound thiamine)	Blood		7.9 - 10.1

			Electrolytes mEq per 1000 ml.	
			Value	Range
27.	Blood electrolytes			
	Magnesium	Blood	1.7	1.6 - 1.8
		R.B.C.	1.2	0.4 - 2.4
		Plasma	1.8	1.0 - 2.3
28.	Blood minor minerals, µg./100 ml.			
	Copper	Blood		820 - 1400

The heart rates were determined for performance tested beef calves (274)(275).

Animal	Heart Rate (beats/min.)	Rectal Temp. (°F)
Angus heifers	100.97	101.69
Hereford heifers	101.98	101.73
Hereford bulls	105.01	101.89
Angus bulls	106.08	101.90

Heart rates differed significantly between sexes and between individuals within sexes. No significant breed differences were noted.

Beef cattle urine volume per 24-hour period is reported as 2500 to 9500 cc., with an average of 5400 cc. (263).

	Volume (cc.)	Weight (lbs.)
Hereford	5,454	12.3
Shorthorn	5,310	11.9
Angus	5,189	11.7

Micturition can be induced by a gentle massage starting below the ventral commissure of the vulva and taking its course upward and laterally terminating beside the labium vulva. Micturition was also induced in a Guernsey steer by a gentle massage below the anus. This procedure is apparently not satisfactory for calves.

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